Meteorological Modeling Analyses of Data Captured During the CRPAQS Field Program

Final Presentation 04-2PM

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CCOS Technical Committee
Sacramento, CA
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STI
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Overview

- Introduction
- Analyses
- Summary and Conclusions
- Recommendations

General Questions

- To what extent can we drive and evaluate diagnostic/prognostic meteorological models using the meteorological data collected?
- Do the simulated meteorology fields represent reality?

Topics Investigated

- Ability of meteorological models to represent important phenomena
- Model evaluation techniques
- Transport pathways
- Adequacy and validity of measurement methods
- Sufficiency of data precision, accuracy, bias, consistency, and time-resolution

Modeling Periods

- CALMET (STI):
  - 12/24/2000 – 12/30/2000
  - 01/03/2001 – 01/09/2001
- MM5 (ARB):
  - 12/14/2000 – 01/08/2001(No FDDA Case)
- Combined:
  - 12/25/2000 – 12/30/2000
  - 01/03/2001 – 01/08/2001

Important Processes

- Stagnation
- Moisture/Fog/Stratus
- Vertical mixing including plume rise
- Recirculation
- Precursor transport (Carbon vs. Nitrate)

Data Analyses

- Statistics (METSTAT)
- Time series plots (T, Q, WS, WD, PBL, VI)
- Spatial plots
- Vertical wind profiles
- Extent of Fog/Stratus
- Soil temperature
- Transport Statistics

METSTAT

- Developed by ENVIRON for TCEQ
- Adjustments to T and WS based on similarity theory
- Issues
- Modifications by Nelson-Gammon (TAMU)
- Modifications by STI
- T_{2m} approximation by linear interpolation

Statistics

1. Hourly mean observations over all sites
2. Hourly mean predictions over all sites
3. Hourly bias (signed error) over all sites
4. Hourly systematic, unsystematic, and total root mean square error (RMSE) over all sites except for wind direction
5. Hourly Index of Agreement (IOA) over all sites except for wind direction
6. Daily mean observations over all hours and sites
7. Daily mean predictions over all hours and sites
8. Daily bias (signed error) over all hours and sites
9. Daily gross error (unsigned error) over all hours and sites
10. Daily systematic, unsystematic, and total RMSE over all hours and sites except for wind direction
11. Daily Index of Agreement (IOA) over all hours and sites except for wind direction

Analysis Regions

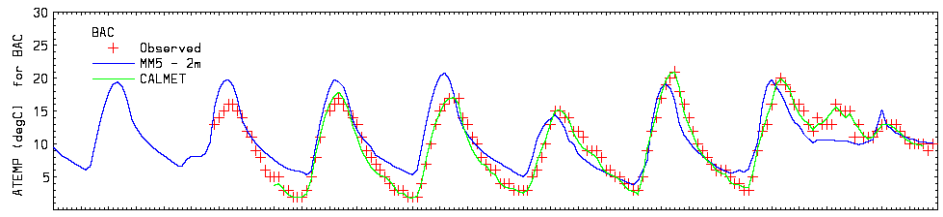
1. Pacific Ocean
2. Northwest California
3. San Francisco Bay Area
4. Central Coast
5. Sacramento Valley North
6. Sacramento Valley South/SJV North
7. San Joaquin Valley Central
8. San Joaquin Valley South
9. Eastern Mountains and Deserts

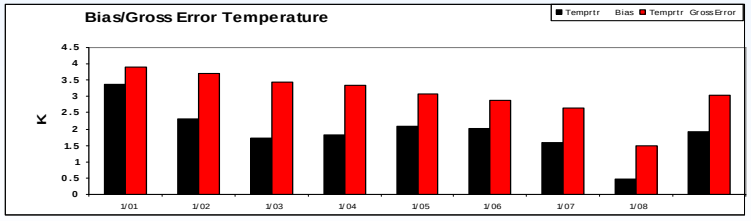
Moisture

- CALMET generally replicates the observed moisture with little or no bias but only provides relative humidity from the site nearest to each grid-cell
- During the first few simulation days, MM5 has a low bias. After 12/20, MM5 generally has a 0.5 g/kg high bias in water vapor mixing ratio
- MM5 trends are generally consistent with observations, but the diurnal cycle is damped (especially in central and southern SJV)) compared to the observations
- Nighttime mixing ratio errors are generally larger than daytime errors
- MM5 usually underpredicts nighttime maxima overpredicts daytime minima
- Errors are quite pronounced (bias approaching 2 g/kg) in the northern Sacramento Valley

Temperature

- CALMET generally replicates the observed temperatures with little or no bias
- MM5 temperatures are biased high through much of the simulation across the Central Valley, SFBA, and central coast
- MM5 often overpredicts both nighttime minimum and daytime maximum temperature
- Nighttime errors are generally larger than daytime errors.
- MM5 generally exhibits a damped diurnal cycle compared to observations





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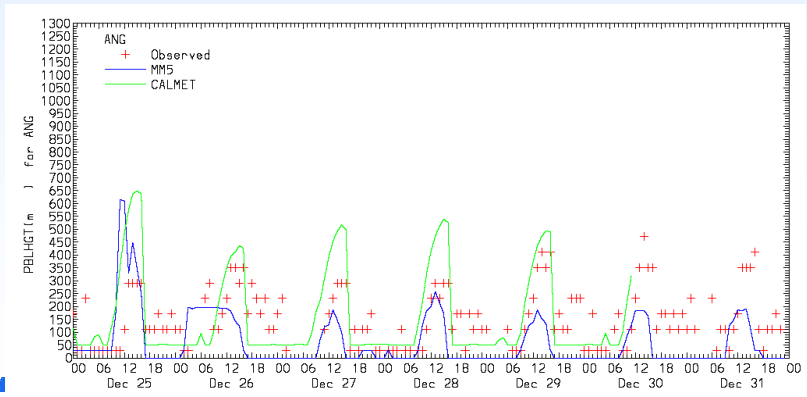
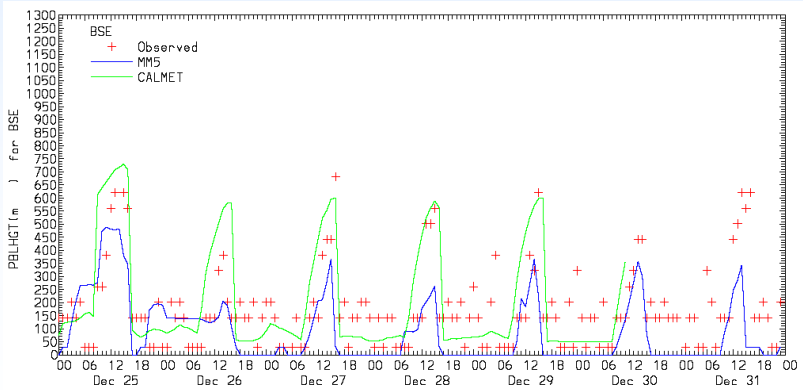
PBL Height

- Both CALMET and MM5 underestimate nighttime PBL heights
- CALMET is biased high during the day but often gets the peak heights correct. However, mid-morning PBL heights rise too rapidly
- MM5 is biased low but often does better than CALMET with the mid-morning rate of increase





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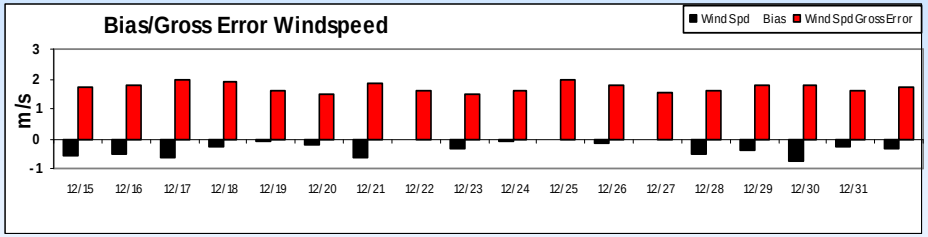
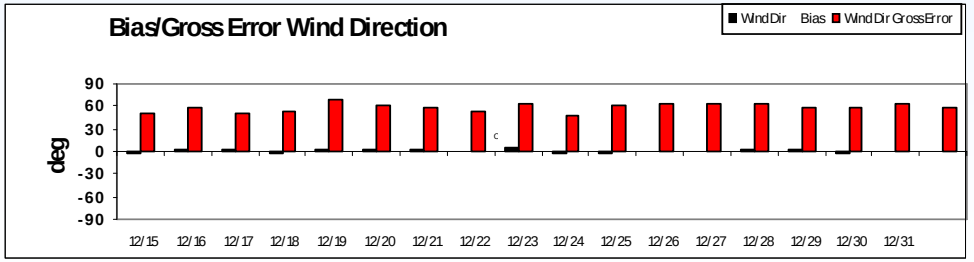
Winds

- CALMET generally replicates the observed winds with little or no bias except in cells near multiple observing sites
- MM5 wind speeds are generally underpredicted (bias ~0.4 m/s overall)



- MM5 wind directions are generally unbiased



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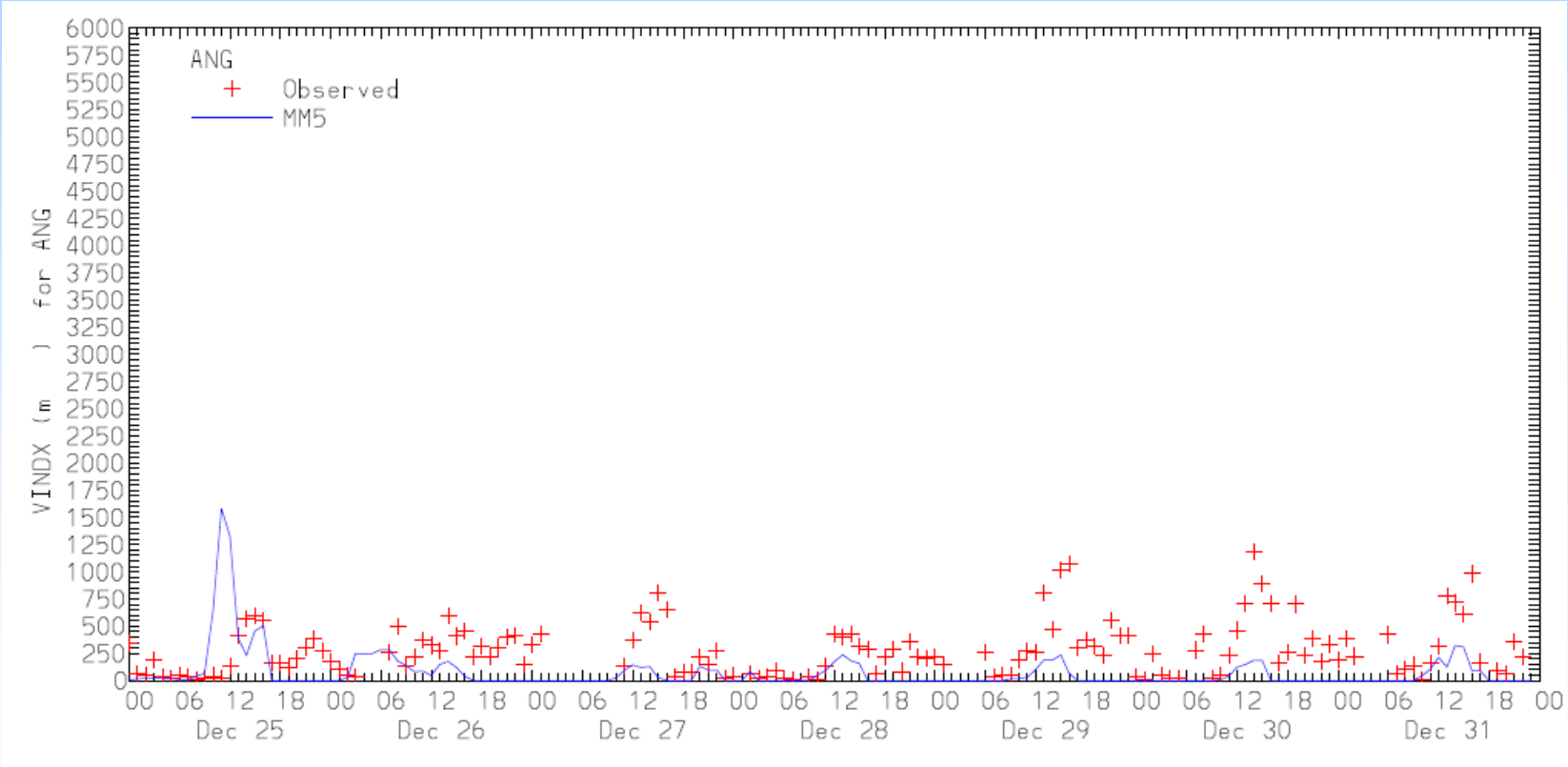
Ventilation Index



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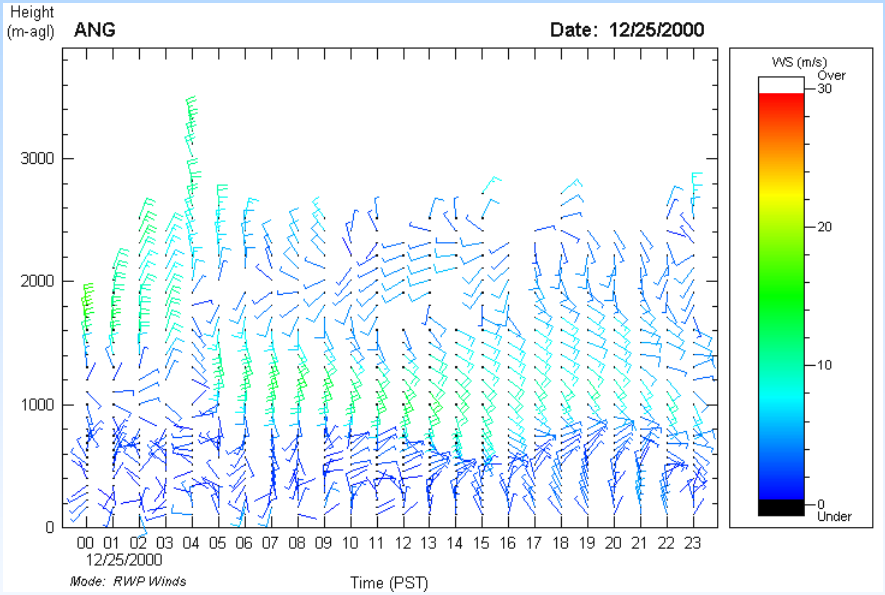
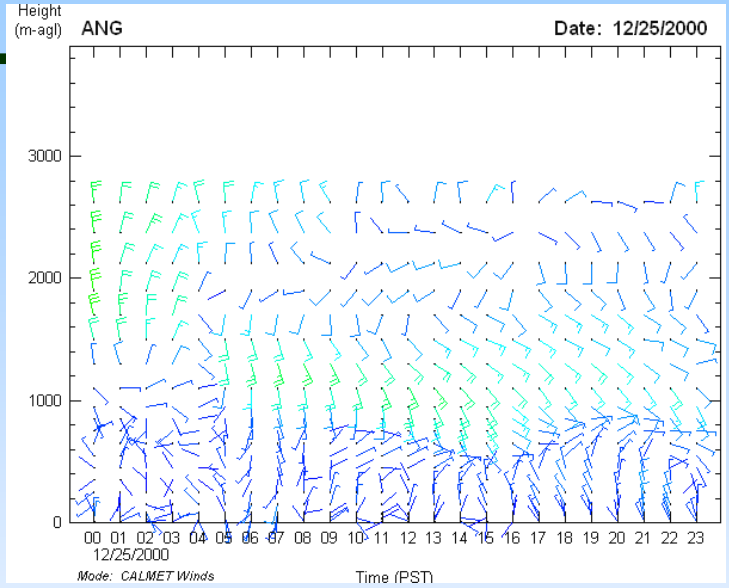
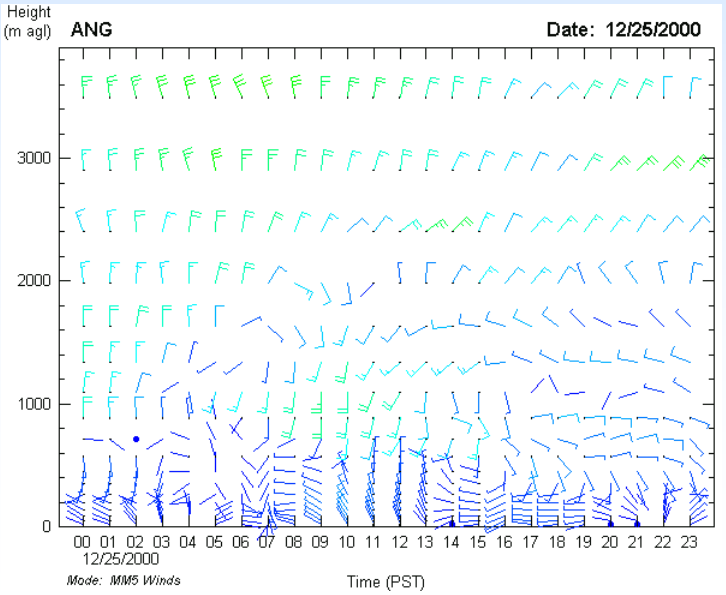
Wind Profiles







Angiola 12/25/2008

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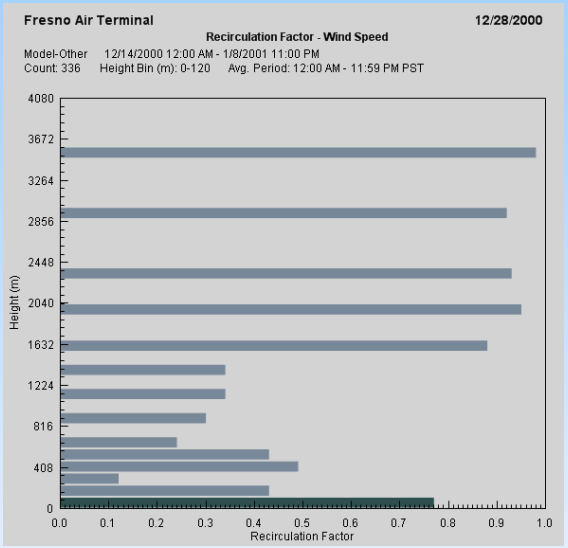
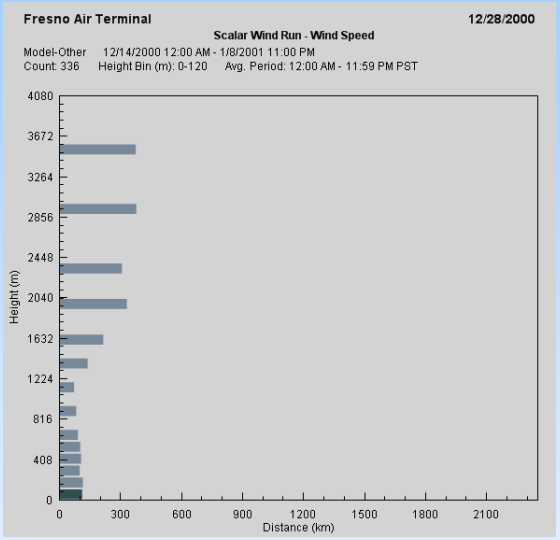
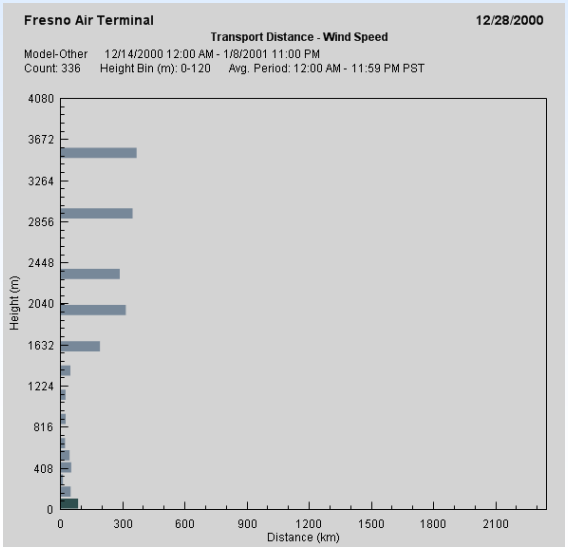
Transport Statistics (1 of 2)

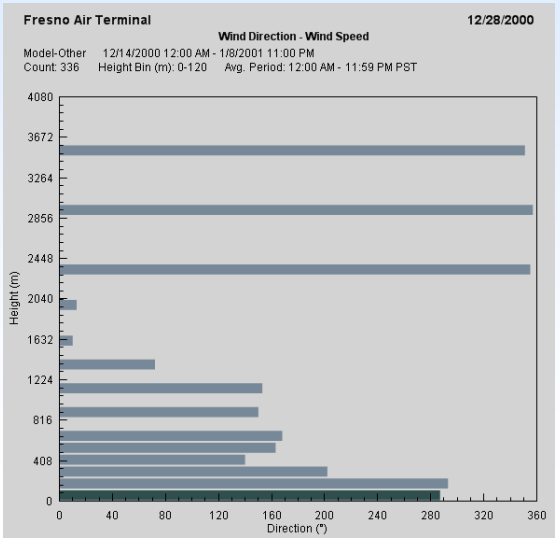
- Statistics:
  - Daily Transport Distance
  - Daily Wind Direction
  - Daily Scalar Wind Run
  - Recirculation Factor
- Calculated at RWP sites by vertical bins
- RWP, CALMET, and MM5 compared

Transport Statistics (2 of 2)









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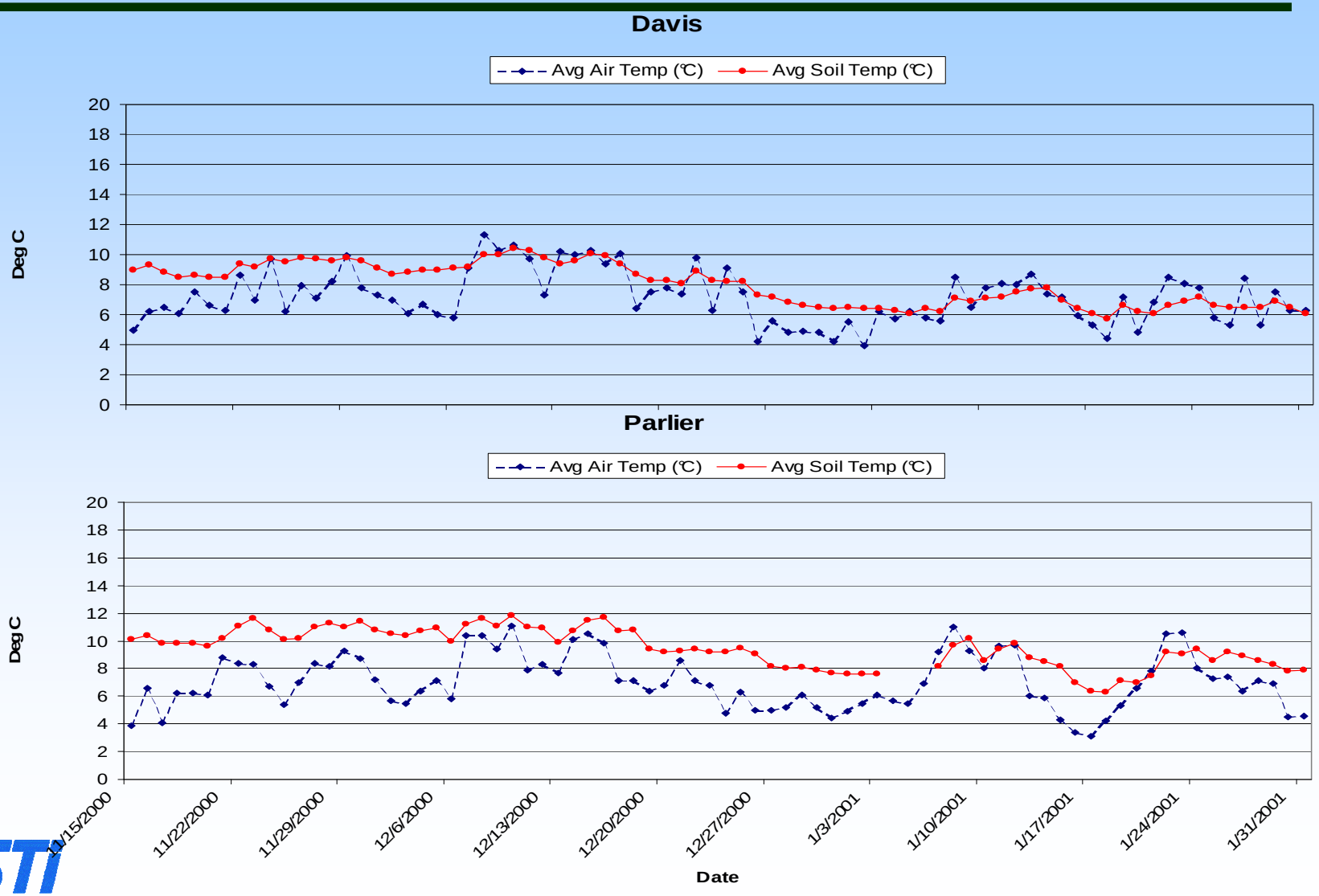
Transport Statistics (3 of 3)

- CALMET
- MM5
- Can not be evaluated where there are no data

Soil Temperature (1 of 2)



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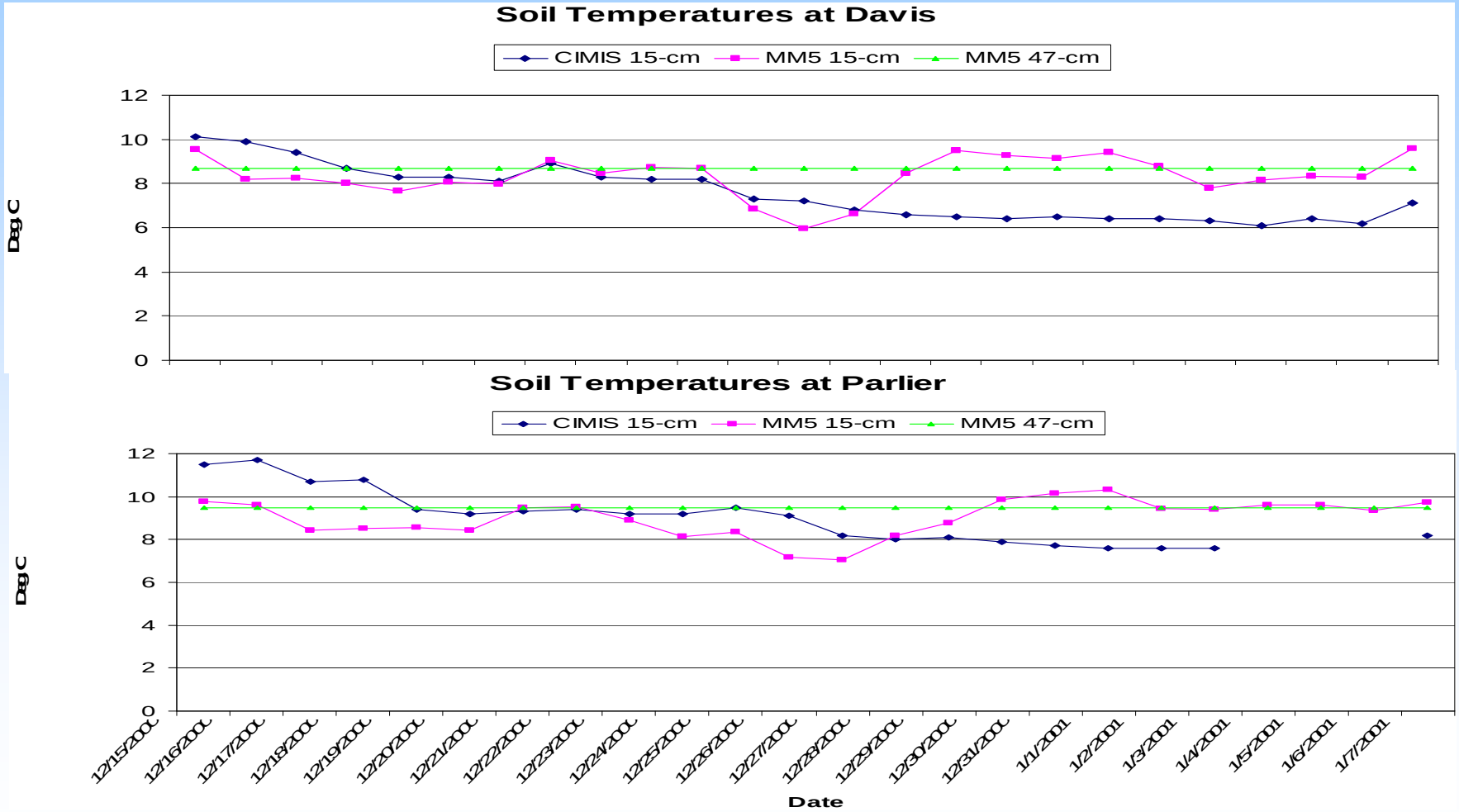
Soil Temperature (2 of 2)



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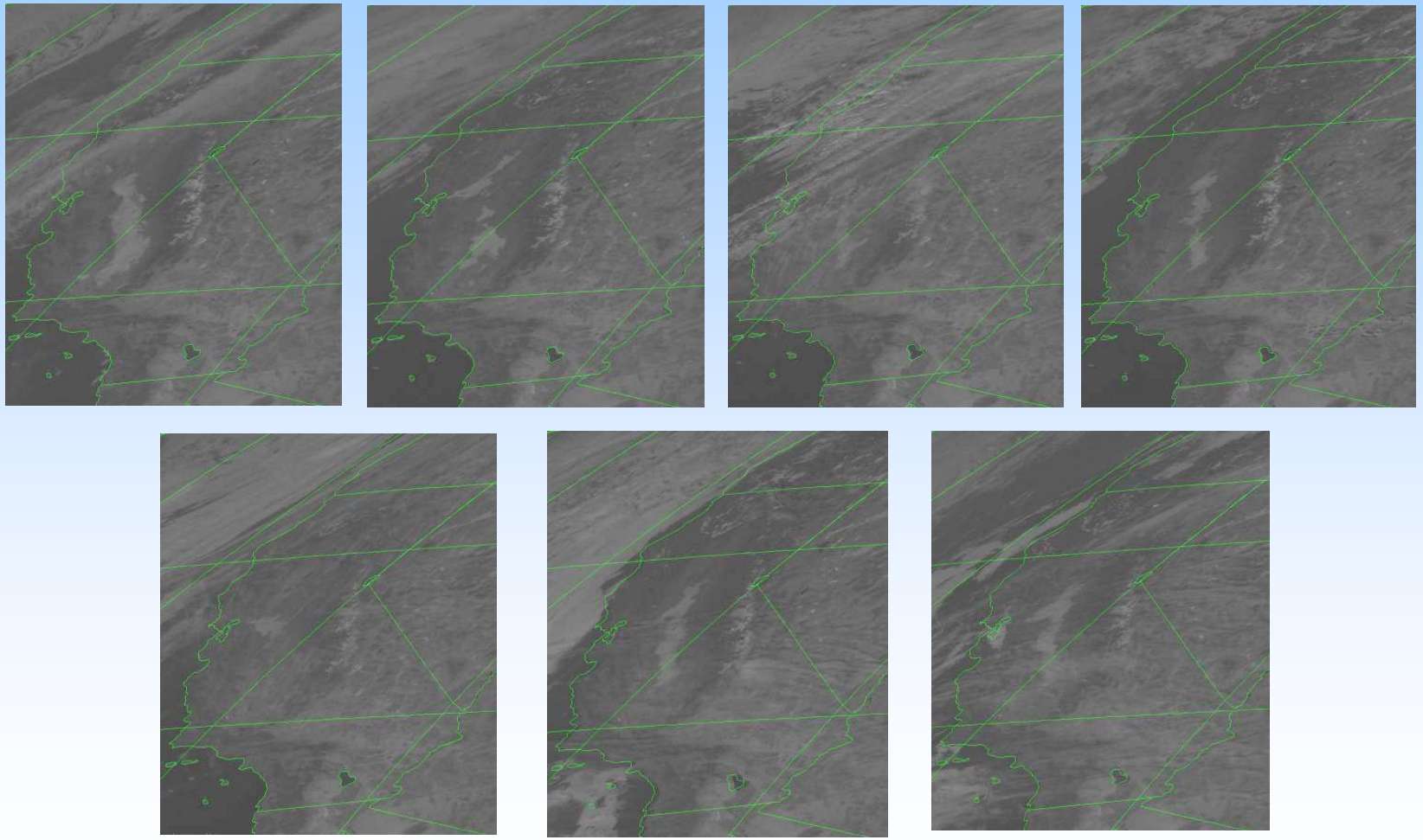
Extent of Fog - Satellite Imagery



Satellite 25-31 December 2000

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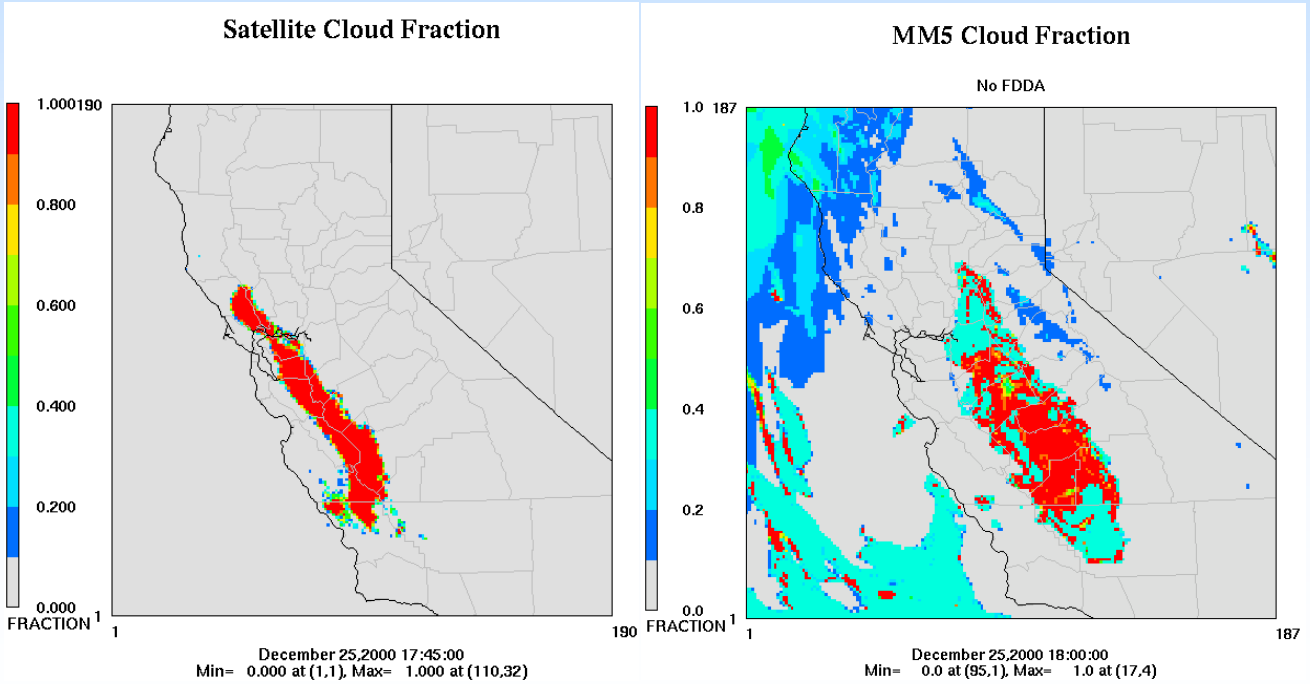
Extent of Fog - Satellite vs. MM5

- CALMET does not predict or output fog or clouds.
- MM5 tends to overestimate the extent of fog/stratus.



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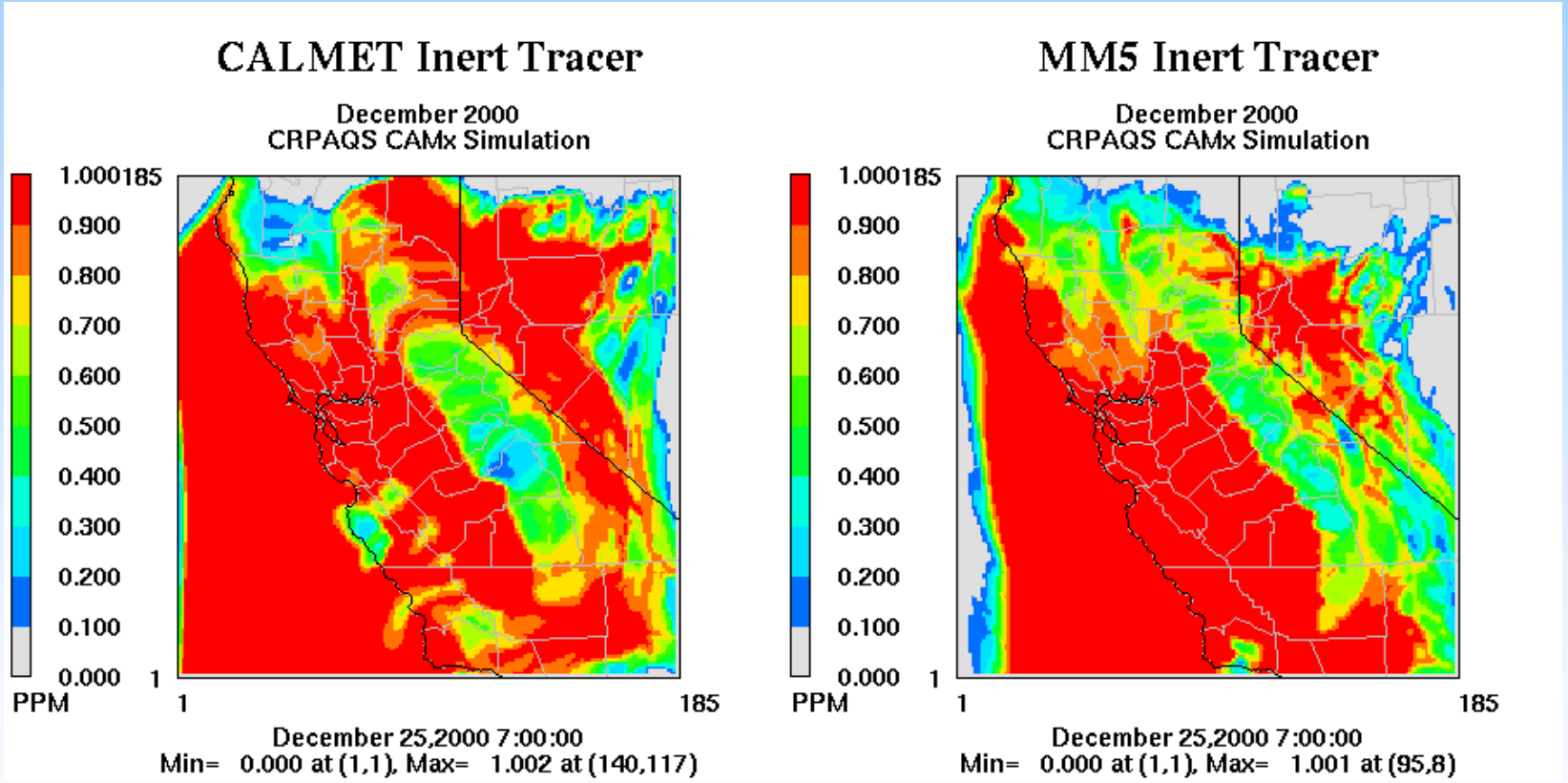
Modeling Analyses

- Tracer Conservation (CALMET, MM5 -> CAMx)
- Tagged Tracer (CALMET, MM5 -> CAMx)
- MM5 Sensitivity
  - Time Step (6 vs. 12 minute)
  - Moisture Availability (25% and 75% reductions)
- Plume Rise (CALMET, MM5 -> CAMx vs. SF6 tracer)

Tracer Conservation

- Purpose: Assess modeling systems' behavior
- CAMx simulations
- Meteorological processing
  - MM5CAMx
  - CMETCAMx
- Initial conditions: 1 ppm of inert tracer
- Emissions and boundary conditions: Zero
- Analysis
  - Surface concentrations
  - Mass balance
  - Peak tracer concentrations by region

December 25: 7 Hours



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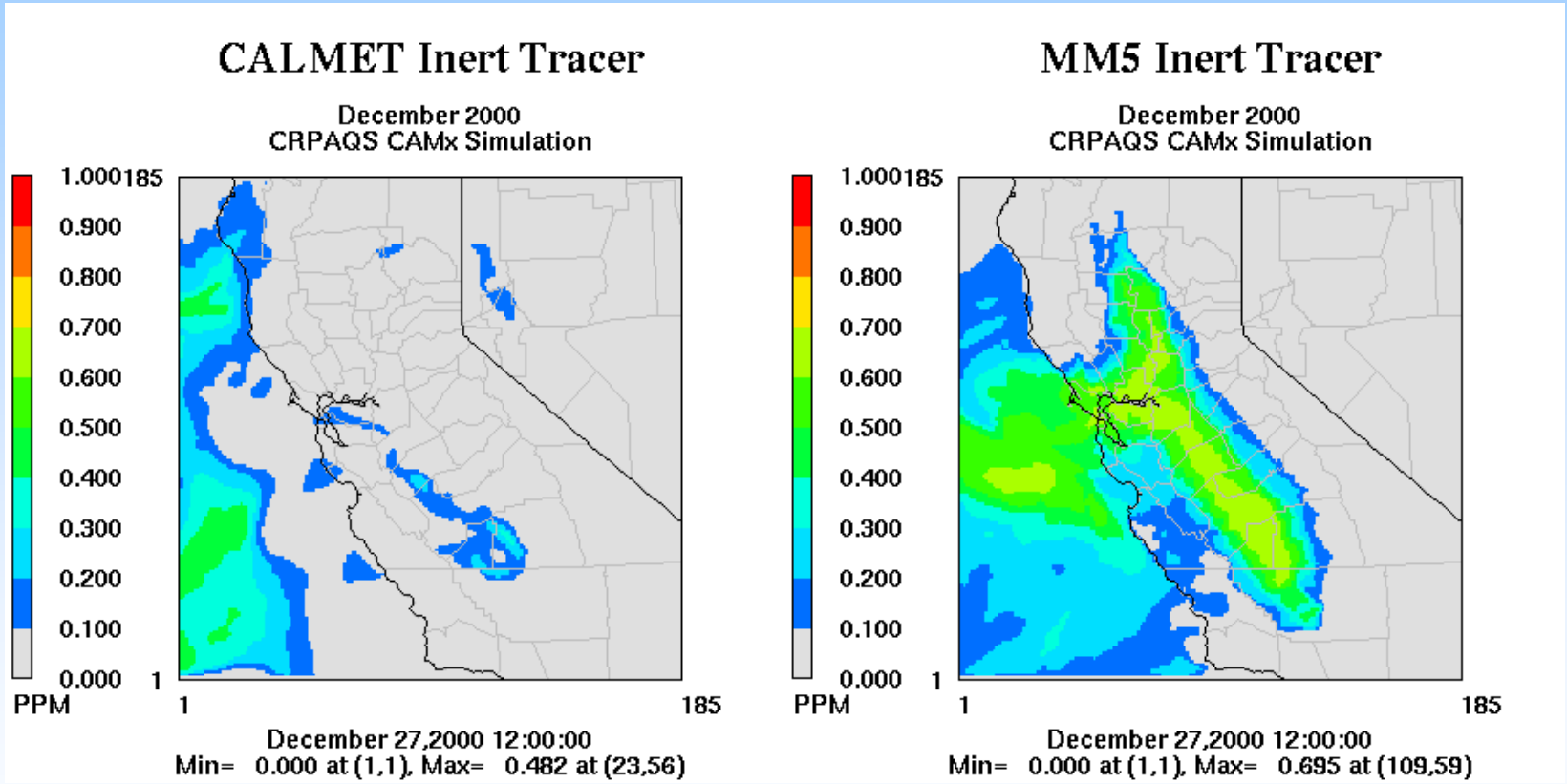
December 27: 60 Hours



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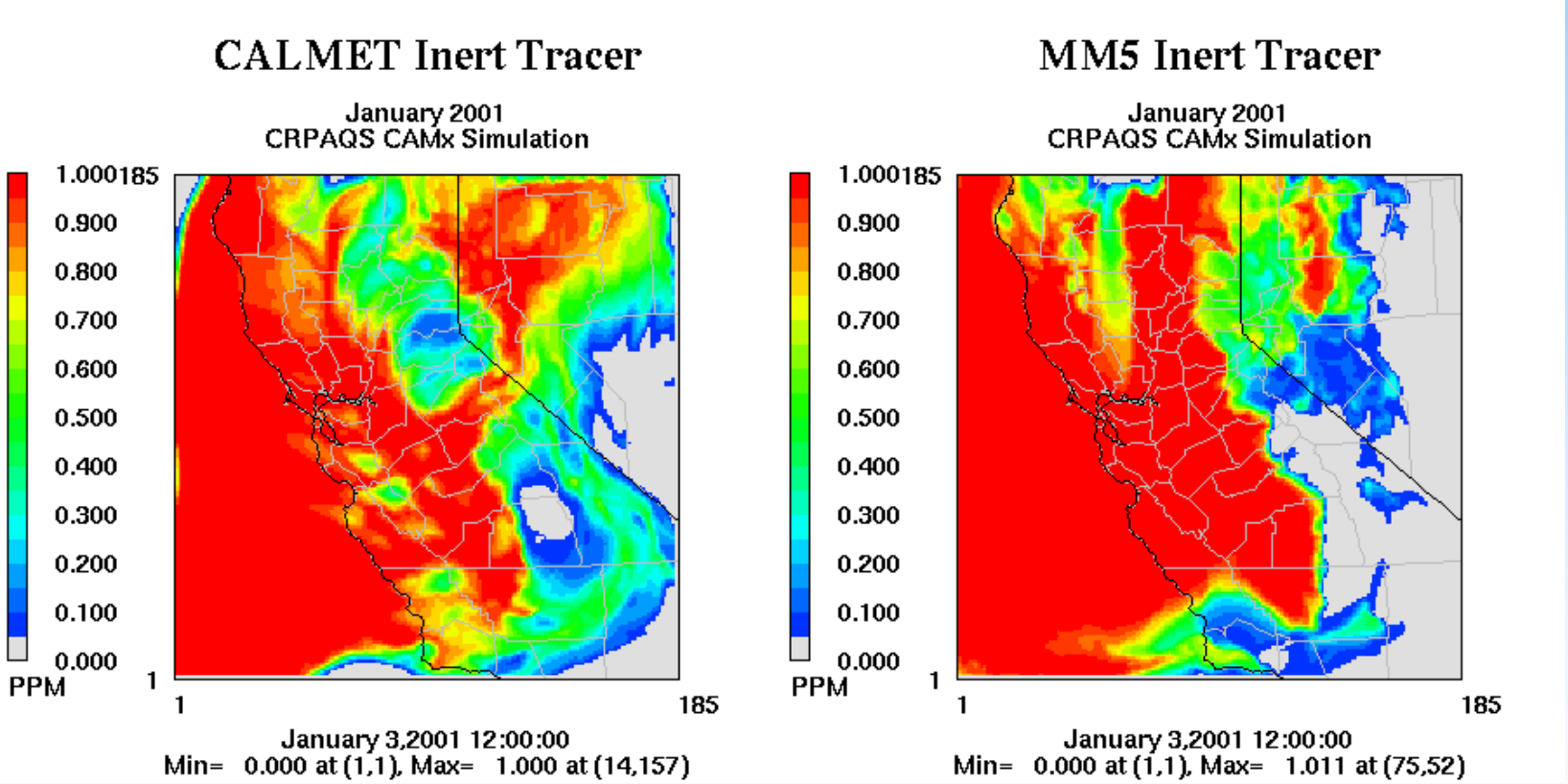
January 3: 12 Hours



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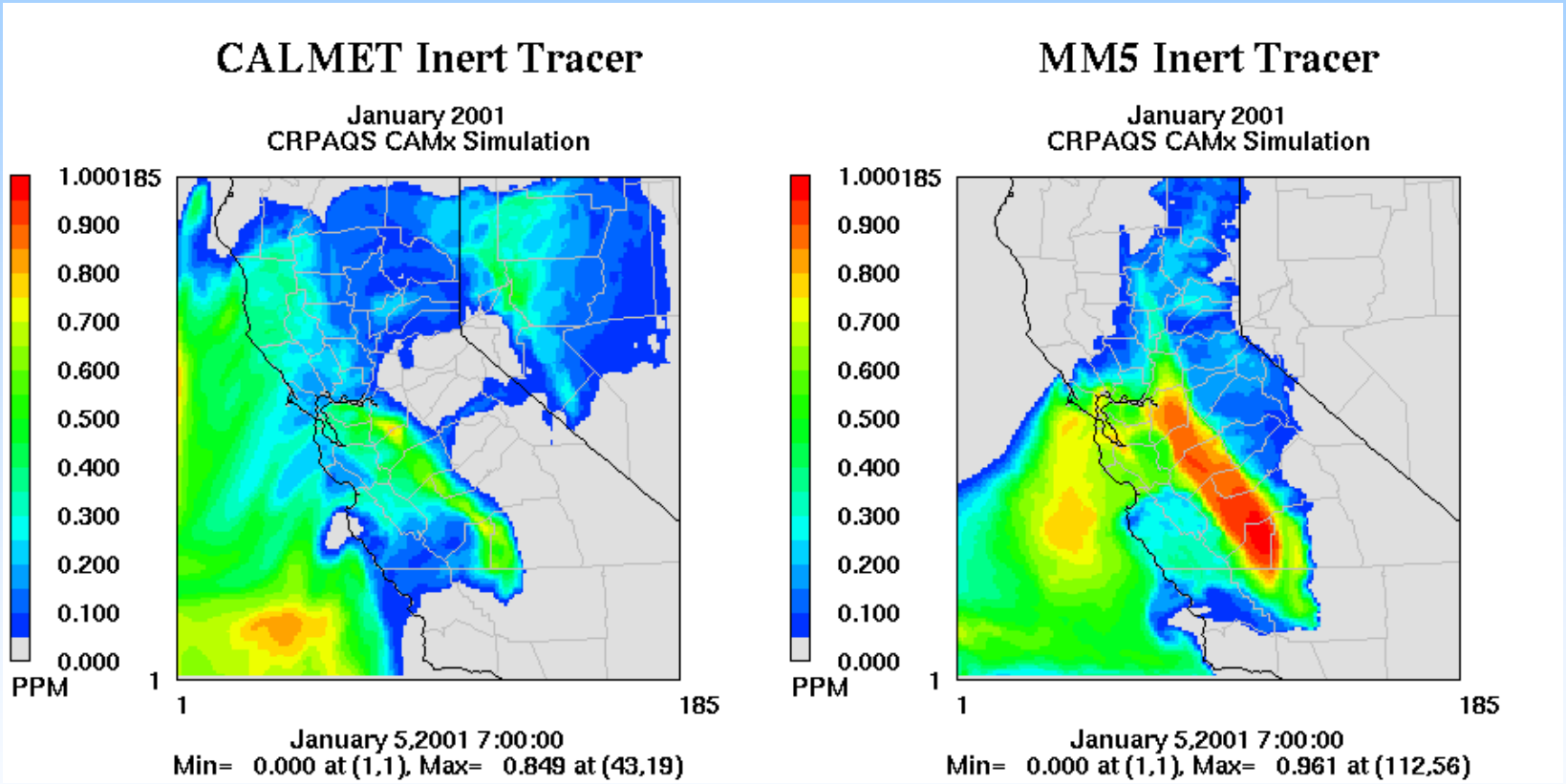
January 5: 55 Hours



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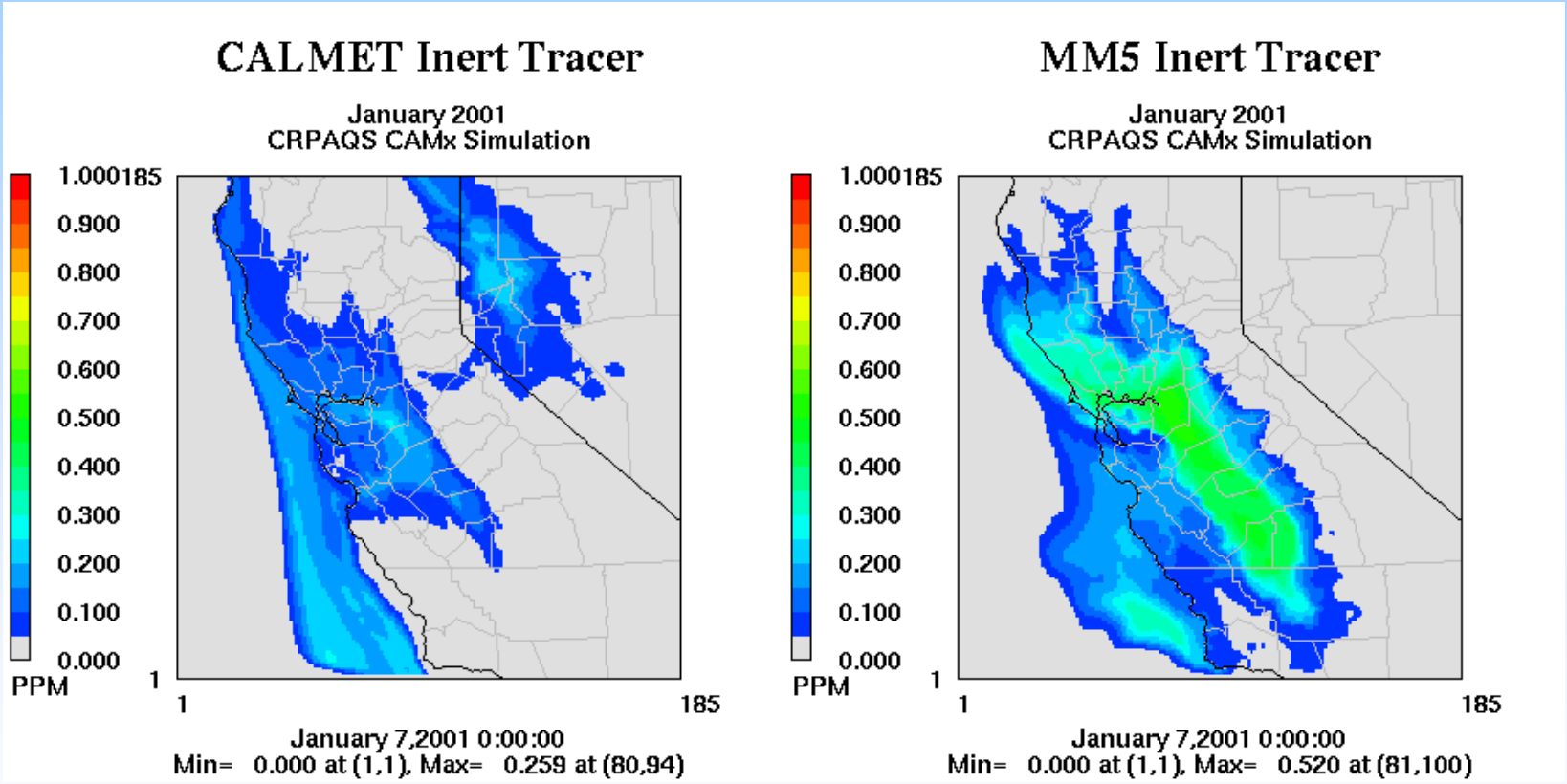
January 7: 96 Hours



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Summary of Tracer Conservation

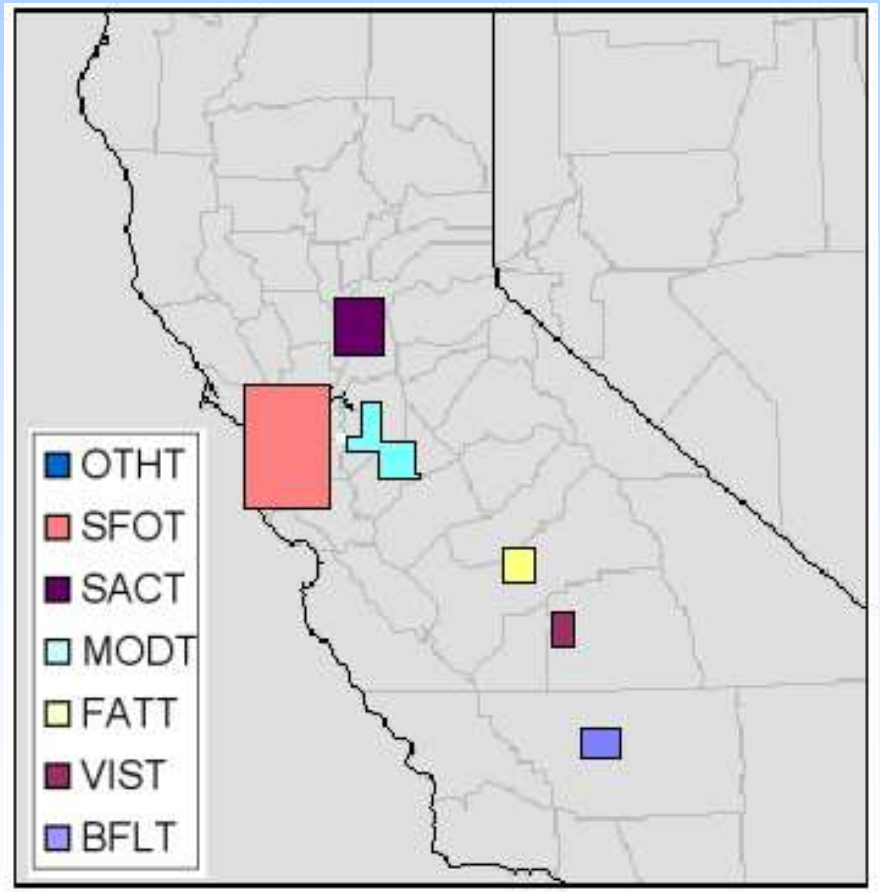
- CAMx loses mass faster with CALMET meteorology than with MM5
- CAMx-MM5 maintains a clearer separation of mass within the Central Valley
- CALMET is losing mass through vertical transport
- Evidence of observation-induced divergence is seen in CALMET, which may be useful for eliminating unrepresentative sites

Transport Analysis

- Tagged Tracers
- Improvement over original data analysis methods
- CAMx Simulations
- Initial and Boundaries Conditions: Zero
- Emissions
  - NO_x emissions mapped as unique inert tracer species to 6 urban areas and 1 “all other” area
- Analysis
  - Surface concentrations
  - Contributions to concentrations at specific sites

Tracer Source Areas

- Sacramento
- San Francisco Bay Area
- Stockton- Modesto
- Fresno
- Visalia
- Bakersfield
- Other



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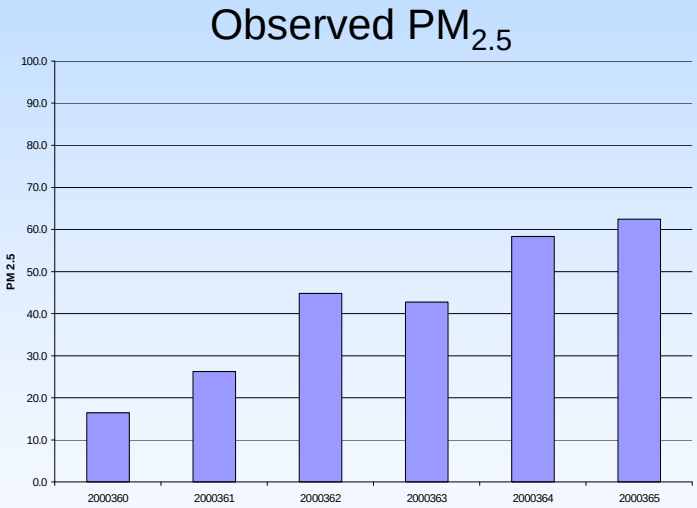
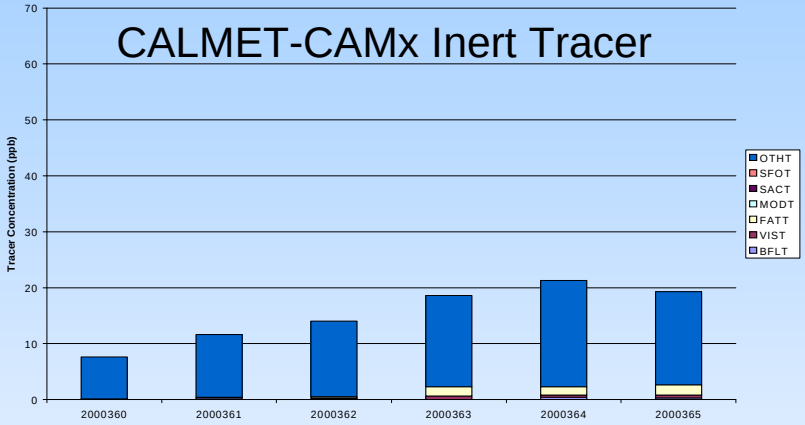
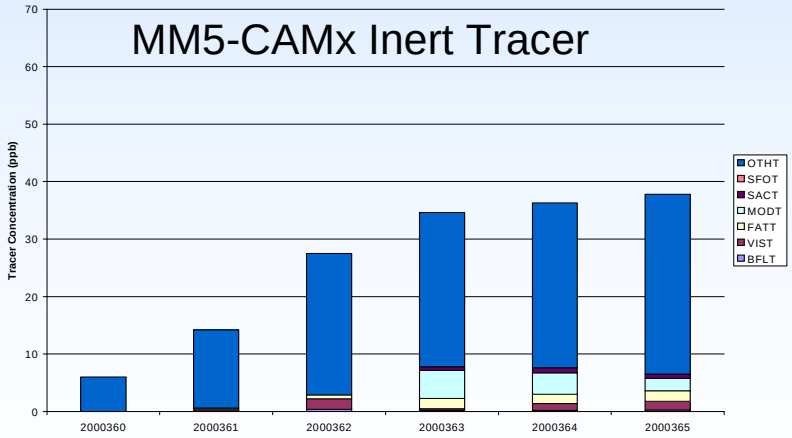
Angiola: December 25-30 2000







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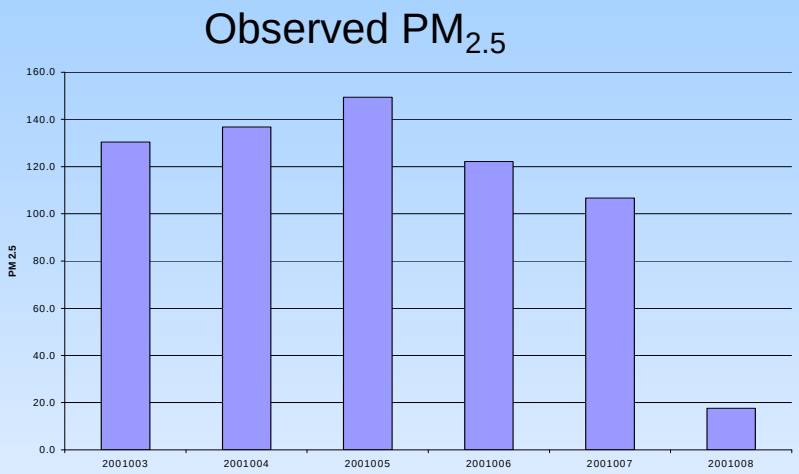
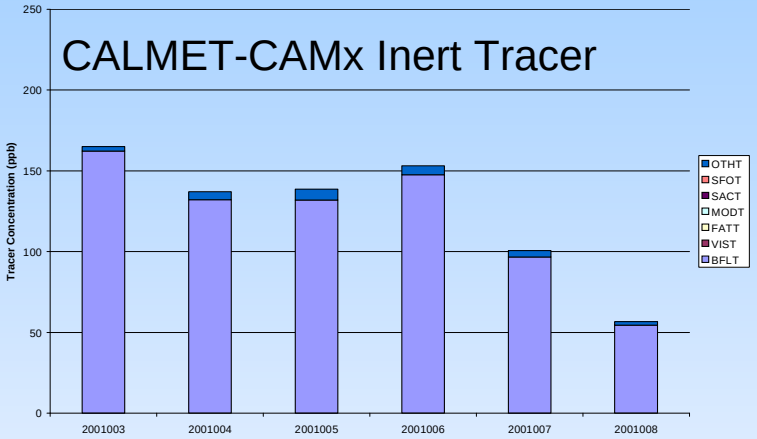
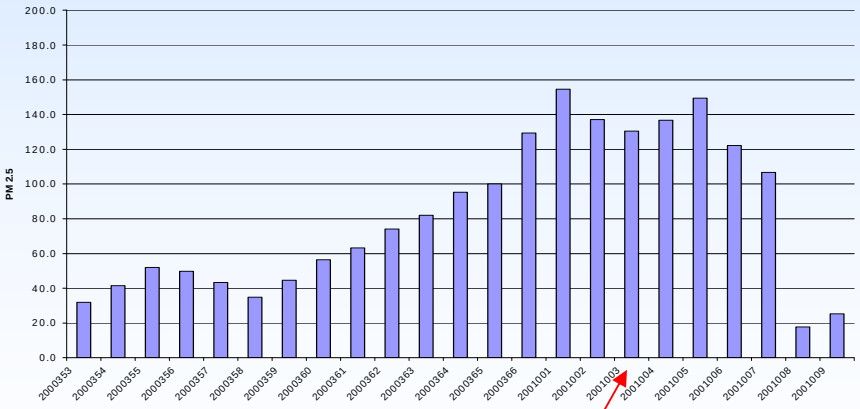
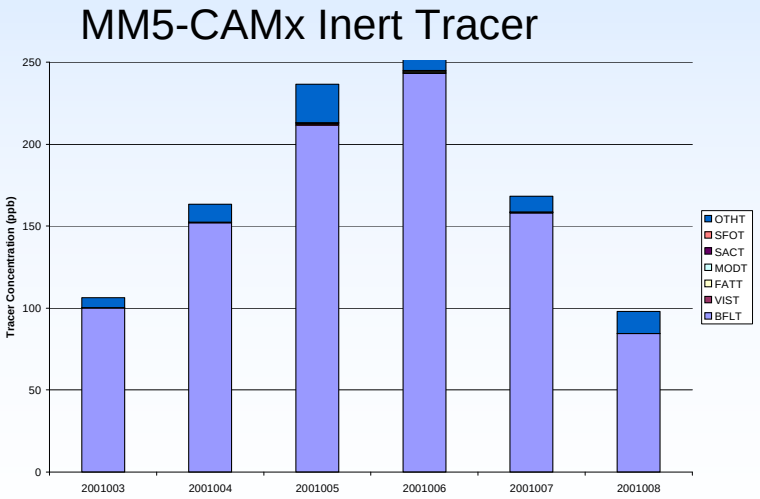
Bakersfield: January 3-8 2001









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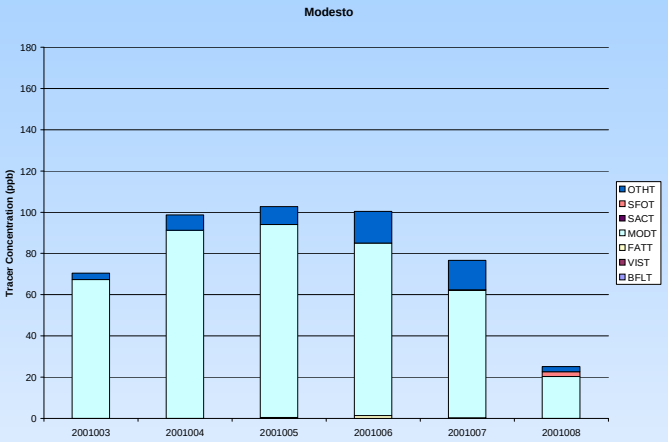
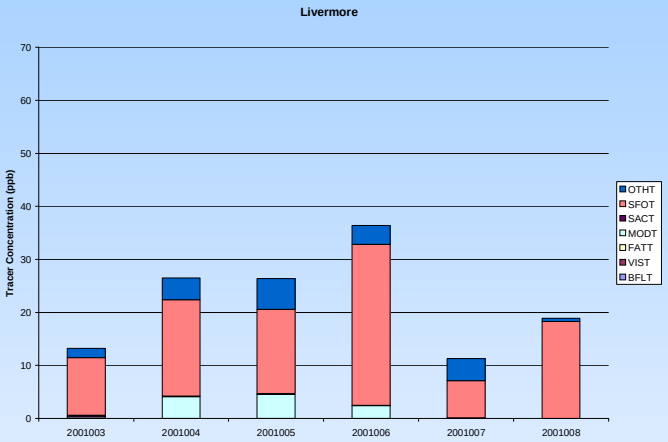
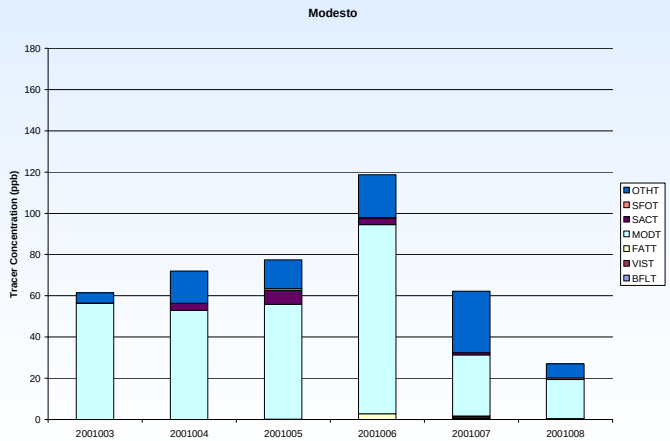
Modesto and Livermore

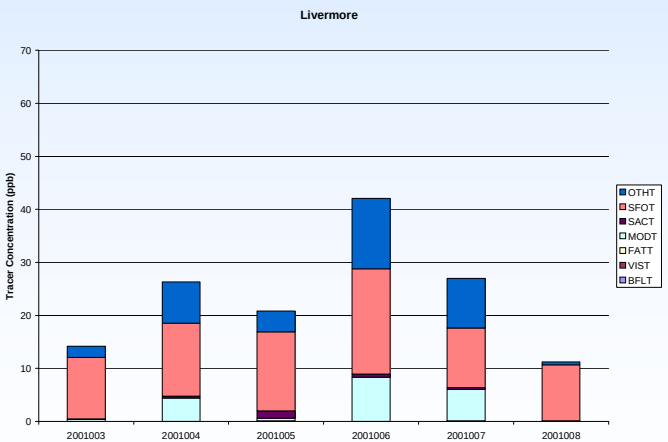
CALMET





MM5





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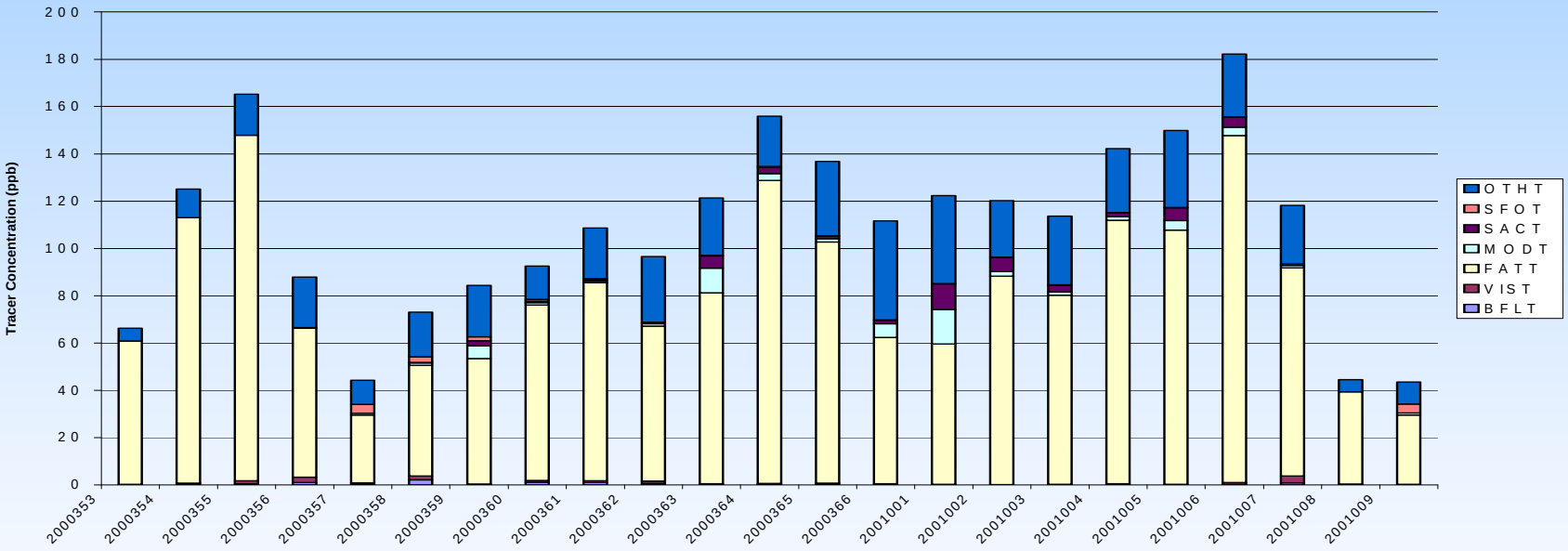
Fresno: MM5-CAMx December 18 – January 9



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Summary of Tagged Tracers

- Local tracer emissions dominate the total tracer concentration although 5 to 30% of the total tracer concentrations at the urban sites are from “rural” areas
- The relative contribution of rural tracers at urban sites is less in CALMET simulations than in the MM5 simulations
- Transport between the SJV, SV, and SFBA air basin occurs on some days but does not dominate most of the analysis period (Inter-basin transport)
- The relative contribution of non-local tracers (i.e., tracers not emitted from the area selected for analysis) is larger in MM5 than in CALMET (Intra-basin transport)

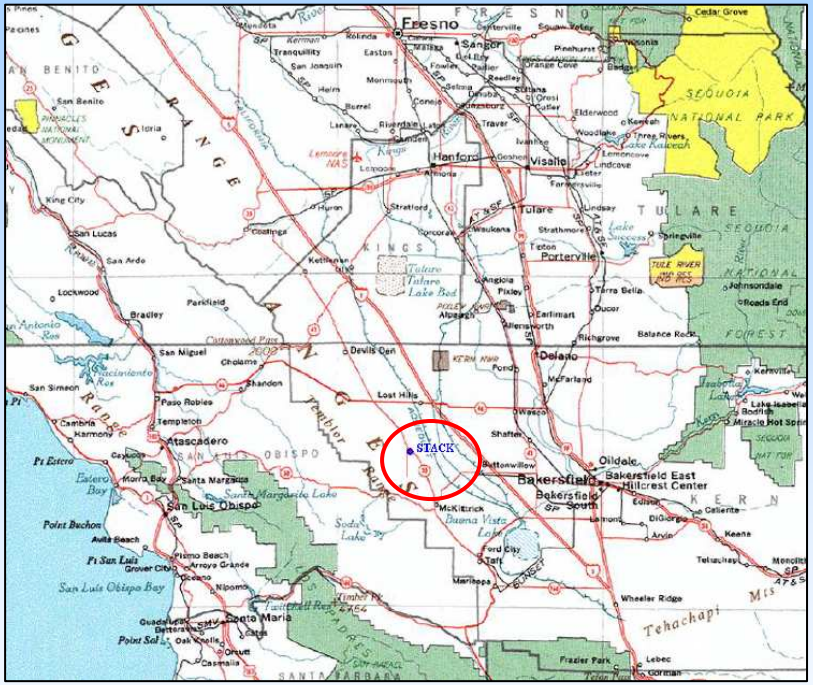
MM5 Sensitivity Simulations

- Time Step (6 vs. 12 minutes)
- Soil Moisture
  - 25% Reduction
  - 75% Reduction
  - Results:
    - Moisture – Improved at 25%
    - Temperature – little change
    - PBL Height – little change
    - Clouds/Fog – little change

Plume Rise

- South Belridge Oil Field
- Clean Airship I
- SF6 Tracer
- CAMx modified to output plume rise
- CALMET and MM5

South Belridge Oil Field



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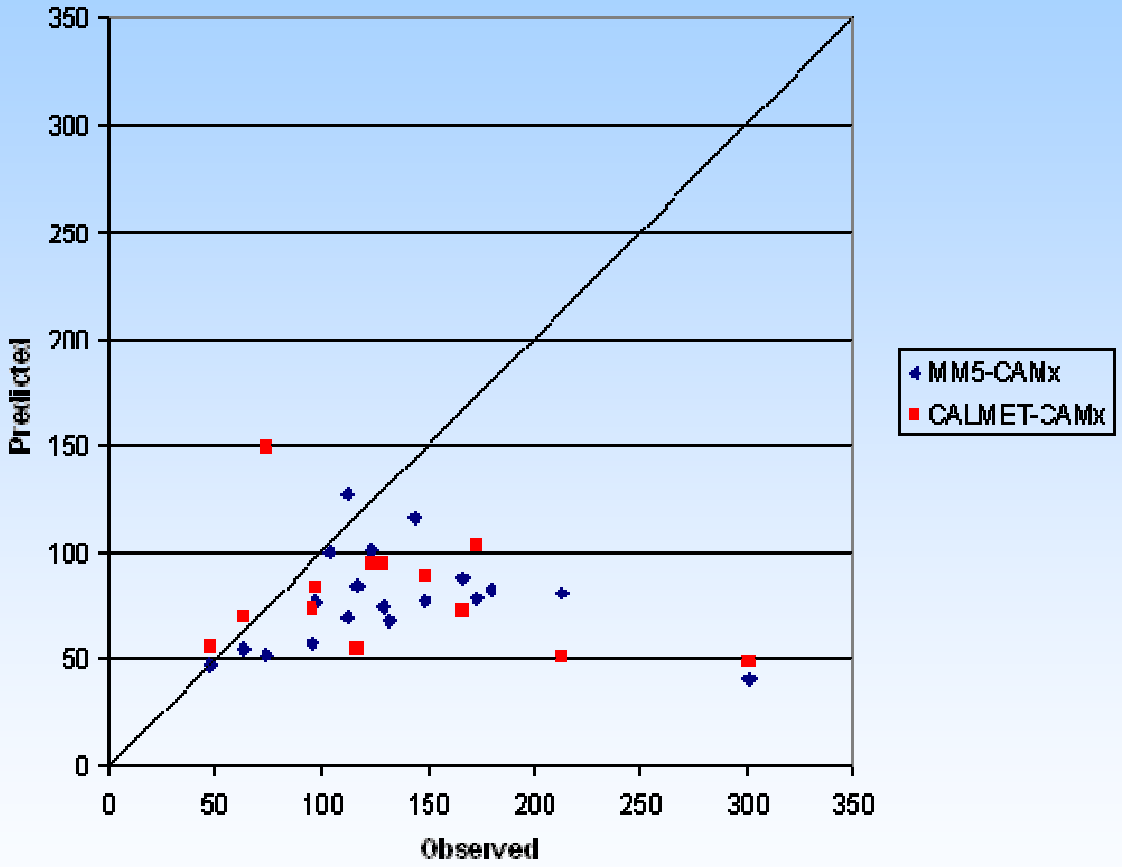
Summary of CAMx Simulations

Simulation Number	Flights	Date	Start Time	End Time	Meteorology	Emission Rates
1	2-3	12/16/2001	1500	1700	MM5	1500-1700: 5.4 lb/hr
2	4-7	12/17/2000	0800	1200	MM5	0800-1000: 5.4 lb/hr 1000-1100: 1.0 lb/hr 1100-1200: 3.2 lb/hr
3	9-14	1/4/2001	0800	1300	MM5	0800-1300: 2.0 lb/hr
4	15-18	1/5/2001	0800	1700	MM5	0800-1000: 2.0 lb/hr 1000-1200: 0.0 lb/hr 1200-1300: 3.1 lb/hr 1300-1400: 0.0 lb/hr 1400-1700: 3.7 lb/hr
5	19-22	1/6/2001	0800	1600	MM5	0800-1000: 3.7 lb/hr 1000-1400: 0.0 lb/hr 1400-1600: 4.3 lb/hr
6	9-14	1/4/2001	0800	1300	CALMET	same as experiment 3
7	15-18	1/5/2001	0800	1700	CALMET	same as experiment 4
8	19-22	1/6/2001	0800	1600	CALMET	same as experiment 5

Observed and Modeled Plume Rise



Comparison of observation-based and model-based plume rise (m)

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Other Plume Analyses

- Vertical Diffusion
- Concentrations
- Horizontal and Vertical Transport and Diffusion

Plume Rise Summary

- Treatment of plume rise under stable nighttime conditions – not addressed in the experiments
- Plume heights calculated in CAMx were generally less than the observed
- Vertical transport and diffusion resulted in SF6 predicted at elevations above those observed
- Nighttime chemistry in the first 200 m agl
- Perform diagnostic simulations to investigate the impact of nighttime plume rise uncertainties on photochemical simulations of aerosol formation

Summary and Conclusions

Modeling Summary (1 of 3)

- CALMET replicates meteorological values at measurement sites but may not correctly represent spatial gradients
- MM5 has biases in temperature, moisture, wind speed, extend of fog, and PBL height that appear be related to land-surface-atmosphere interactions
- MM5 diurnal patterns of moisture, temperature, and PBL height do not match observed patterns
- CALMET-CAMx appears to lose mass too fast from the Central Valley

Modeling Summary (2 of 3)

- CALMET might be improved by more selective use of observational data but it is not clear if interpolation-induced divergence can be eliminated
- MM5-CAMx maintains mass in the Central Valley longer than CALMET-CAMx but predicts greater non-local contributions to inert-tracer concentrations (even though it underestimates wind speeds)
- Significant modifications to CALMET would be required to provide the spatially varying (vertical and horizontal) moisture fields required by photochemical aerosol models

Modeling Summary (3 of 3)

- Daytime plume rise in CAMx is underestimated using both CALMET and MM5 meteorology
- Adjustments to the MM5 moisture availability can reduce biases on moisture prediction but do little to improve the diurnal range and evolution of moisture, temperature, and PBL height

Conclusions

- Adequacy and validity of measurement methods
  - Traditional
  - RWP
  - SODAR
- Sufficiency of data precision, accuracy, bias, consistency, and time-resolution
- Spatial representativeness

Conclusions

- Ability of models to represent important phenomena
  - Stagnation
  - Moisture/Fog/Stratus
  - Vertical mixing including plume rise
  - Recirculation - horizontal and vertical
  - Precursor transport – Ambiguous Nitrate

Conclusions

- Model Evaluation Techniques
  - Conservation of tracers
  - Integrated and summary metrics
  - Extent of fog and clouds
  - Soil temperature and moisture
- Transport Pathways
  - Intra-basin
  - Inter-basin
  - CALMET vs. MM5

Recommendations (1 of 2)

- Use a land surface model in future MM5 simulations - Issues
- Use FDDA in MM5 simulations
- Selectively reduce the number of sites used for objective analysis or data assimilation
- Consider using WRF in future simulations
- Meteorological and Photochemical modeling and evaluation should be an integrated process

Recommendations (2 of 2)

- Model Performance Evaluation
  - Better geo-referencing of satellite images and greater automation for extent of fog analysis
  - Improve methods addressing commensurability
  - Unify and standardize MPE tools
  - Use integrated methods: tracers and combination metrics
- CALMET vs. MM5
- More research on nighttime mixing processes
- Make meteorological model evaluation products available for $PM_{2.5}$ model evaluations